The Zipper Element: A Displacement Discontinuity Element Used Between Shells to Model Brittle Damage[1]

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Abstract

Rate–independent damage–evolution constitutive relationships for brittle materials, such as high–modulus graphite fiber reinforced epoxy (Gr/Ep), impose very strong restrictions on element sizes when normalized to yield mesh independent results. The maximum element dimension perpendicular to the damage zone or "crack" cannot exceed l_f, the material's characteristic failure length. This length, expressed in terms of the material's failure strength (σ_f), failure strain (ϵ_f), and associated damage energy ($\mathcal{G}$), is given by $l_f = 2\mathcal{G}/\sigma_f\epsilon_f$. The resultant element size restriction renders large–scale explicit finite element simulations of high–modulus Gr/Ep structures infeasible due to the large number of elements required and the corresponding time step size.

A shell like "zipper" element has been developed as an alternative approach to incorporating brittle damage mechanisms within the constitutive relationship. Unlike enhanced strain formulations (ESF) that embed the displacement discontinuity directly within the element (*e.g.* Simo, Oliver, & Armero, 1993), the zero-width zipper element accommodates only the displacement discontinuity and is positioned between adjacent shell elements. Similar to ESF, it utilizes a traction–displacement "constitutive" relationship to represent the damage evolution. The zipper element is fully consistent with fracture mechanics, *i.e.* it can be viewed as a modified Dugdale zone (Dugdale, 1960) within the context of small scale yielding, and it is conceptually similar to elements previously developed to model the separation of shells (*e.g.* Flanagan, 1993).

Key aspects of the zipper element implementation are discussed. Trapezoidal element integration permits easy implementation of a rigid–damaging traction–displacement idealization. This eliminates all zipper imposed time step constraints in the pre–damaged region. For the damaged region, bounds are developed for the element's eigenvalues, and sub-cycling approaches are explored. Finally, limited numerical simulations are presented.

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